

REMARKS

Claim 1 has been amended to incorporate therein the recitation of claim 9. Claims 5 and 9 have been canceled. Claims 10, 19 and 21 have been amended to conform with the amendment to claim 1. Claim 7 has been amended to delete unnecessary language. Withdrawn apparatus claims 23-26 have been canceled. Applicants reserve the right to file a divisional application directed to the canceled subject matter.

New claim 27 includes the feature of supplying a second gas containing no oxygen or containing oxygen in amount of 1 pbb or less into the plasma chamber around the opposed electrodes. This embodiment of the invention is described, for example, in paragraphs [0151] to [0154] and Fig. 15(a) and (b) of Applicants' published U.S. application. New claim 28 depending from claim 7 recites that the nitrogen gas introduced between the pair of opposed electrodes contains oxygen or an oxide in an amount of 50 ppm or higher and equal to or lower than 0.2%. Support for the lower limit of 50 ppm is found by reference to Fig. 37 and paragraph [0232], where oxygen gas is introduced at a flow rate of 0.5 sccm.

Review and reconsideration on the merits are requested.

Claims 1, 3, 5, 6, 7, 9, 10, 12, 14, 16, 19 and 21 were rejected under 35 U.S.C. § 103(a) as being unpatentable over JP 2002-324795 (JP '795) to Hinonari in view of U.S. Patent 4,671,813 to Yoshino. Hinonari was cited as disclosing the method substantially as claimed, which includes introducing a nitrogen-containing gas between a pair of opposed electrodes in the vicinity of atmospheric pressure, applying an electric field to the gas and contacting a silicon wafer with the resulting plasma to form a silicon nitride film thereon. The Examiner acknowledged that Hinonari fails to disclose the presence of oxygen or an oxide at higher than 1 ppm and equal to or lower than 0.2% in the nitrogen gas, and subsequent formation of silicon

oxynitride. The Examiner relied on Yoshino as disclosing that nitrogen gas used in the electronics industry contains from 5 to 1,000 ppm of oxygen impurity, citing col. 5, lines 60 - col. 6, line 12. The reason for rejection was that it would have been obvious to use the nitrogen gas of Yoshino containing the oxygen impurity as the nitrogen-containing gas in the technique of Hinonari so as to form an oxynitride.

Applicants traverse, and respectfully request the Examiner to reconsider in view of the amendment to the claims and the following remarks.

1. Features of the Present Invention

An object of the present invention is to form a uniform oxynitride film by low-temperature and high-speed nitriding reaction under atmospheric pressure, without a nitriding time or temperature dependence of nitriding reaction (see paragraph [0012] of Applicants' published specification).

In order to form such a "uniform oxynitride film by low-temperature and high-speed nitriding reaction, without a nitriding time or temperature dependence of nitriding reaction," the invention takes the following measure.

- A "plasma in which an N₂ (H.I.R.) and/or N₂ (2nd p.s.) active species appears dominantly" as active nitrogen species observed by optical emission spectroscopy is brought into contact with an object to be processed so as to form an oxynitride film on a surface of the object to be processed.

In order to obtain such "plasma in which an N₂ (H.I.R.) and/or N₂ (2nd p.s.) active species appears dominantly" under atmospheric pressure, the invention takes the following measure.

- A solid dielectric is provided on at least one of opposed surfaces of a pair of electrodes opposed to each other under nearly atmospheric pressure; a nitrogen

gas containing oxygen or an oxide at higher than 1 ppm and equal to or lower than 0.2% is introduced into a space between the pair of opposed electrodes; and an electric field is applied to the nitrogen gas.

According to the aforementioned features of the present invention, the processing gas used is a general-purpose high-purity nitrogen gas not requiring rare gas mixing, component control, or the like. Accordingly, the invention enables the use of the high-purity nitrogen gas, as is, without requiring mixture ratio adjustment, which in turn leads to a reduction in cost and facilitates implementation.

2. Response to Prior Art Rejection

(1) Regarding Hironari (JP 2002-324795):

(1-1) The invention of Hironari is directed to the fabrication of a nitride film, and not to an oxynitride film,

(1-2) Hironari discloses “a method of performing a nitriding treatment of a silicon wafer where a solid dielectric is installed on the opposing surface of the electrode on at least one side of a pair of electrodes opposing to each other under the pressure in the vicinity of the atmospheric pressure and nitrogen-containing gas is introduced between the pair of the electrodes opposing to each other to apply a pulse-shaped electric field to the gas, whereby an obtainable plasma is brought into contact with the silicon wafer and a silicon nitride film is formed on the surface of the silicon wafer.”

(1-3) With respect to the “nitrogen-containing gas” used as a processing gas, Hironari describes the following in claim 2 and paragraphs [0017] and [0018].

[0017]

The nitrogen-containing gas used as a processing gas in formation of a silicon nitride film of the present invention is preferably a nitrogen gas or a mixed gas of a nitrogen gas and an inert gas. Examples of an inert gas include argon, neon, xenon, and helium. Such gas may be used solely or in combination with two or more kinds. The content of a nitrogen gas in the nitrogen-containing gas is preferably 10 to 100% by volume, and more preferably 20 to 100% by volume. The present invention is characterized in that the process can be carried out even with a 100% nitrogen gas.

[0018]

Note that in the present invention, the processing gas preferably contains no oxygen atoms, hydrogen atoms, or halogen atoms. Among them, hydrogen such as Si-H bonds or N-H bonds would inevitably be mixed into a film if a conventional thermal oxidation method that uses NH_3 is employed. This results in a decrease in heat resistance. To the contrary, if the process is carried out in the atmosphere of a nitrogen gas or a mixed gas of a nitrogen gas and an inert gas with the method of the present invention, a SiN film with excellent heat resistance can be provided.

(1-4) That is, Hironari discloses using a 100% nitrogen gas (a mixed gas of a 100% nitrogen gas and 0% inert gas) or using a mixed gas of a nitrogen gas and an inert gas for the process.

However, Hironari neither discloses nor suggests the content of oxygen or oxide in the nitrogen gas, and only the following description is found: **“the processing gas preferably includes no oxygen atoms, hydrogen atoms, or halogen atoms”** (paragraph [0018]).

Thus, Hironari does not presume using a general-purpose high-purity nitrogen gas containing oxygen or oxide.

(1-5) With respect to the “plasma” brought into contact with the object to be processed (silicon wafer), Hiroaki only discloses the following.

“plasma obtained by installing a solid dielectric on the opposing surface of the electrode on at least one side of a pair of electrodes opposing to each other under the pressure in the vicinity of the atmospheric pressure and introducing nitrogen-containing gas between the pair of the electrodes opposing to each other to apply a pulse-shaped electric field to the gas.”

That is, Hironari only discloses using the “atmospheric pressure plasma method” based on the “pulse plasma method using plasma obtained by applying an electric field in pulse form” for the nitriding treatment of a silicon wafer.

Hironari neither discloses nor suggests that the plasma brought into contact with the object to be processed (silicon wafer) is a “plasma in which an N₂ (H.I.R.) and/or N₂ (2nd p.s.) active species appears dominantly under nearly atmospheric pressure.”

(1-6) Thus, even if those skilled in the art could understand from the document of Hironari the use of the atmospheric pressure plasma method (AP plasma) based on the pulse plasma method for the nitriding treatment of a silicon wafer, they cannot readily arrive at the following features of the present invention:

- A “plasma in which an N_2 (H.I.R.) and/or N_2 (2nd p.s.) active species appears dominantly” is brought into contact with the object to be processed so as to form an oxynitride film on a surface of the object to be processed.
- The “plasma in which an N_2 (H.I.R.) and/or N_2 (2nd p.s.) active species appears dominantly” is obtained by a pulse plasma method under nearly atmospheric pressure, using a nitrogen gas containing oxygen or an oxide at higher than 1 ppm and equal to or lower than 0.2%.

(1-7) Hironari discloses the following three working examples in paragraphs [0047] to [0053].

[0047] Example 1

A SiN film was formed on a silicon wafer (200 mm ϕ) using the apparatus shown in Fig. 2. A parallel plate opposed-type long nozzle was formed by spray-coating each of the electrodes 2 and 3 made of aluminum with the solid dielectric 4 made of alumina, so that a slit of the plasma outlet had a gap of 2 mm and the distance till the silicon wafer was 5 mm.

[0048]

A 100% nitrogen gas was introduced as a processing gas from the gas inlet 5 at a flow rate of 10l/min, and a voltage of 20 kV with a frequency of 20 kHz and with a pulse waveform and a pulse rise/fall time of 5 μ s shown in Fig. 1(a) was applied to a space between the electrodes 2 and 3 to cause electric discharge under a pressure of 95 kPa (atmospheric pressure), so that plasma was generated. The resulting plasma was blown to the silicon wafer heated to 400°C so as to process the silicon wafer.

[0049]

It was confirmed that a SiN film with a thickness of 1 nm was formed on the processed silicon wafer in a processing time of 40 minutes. The observation of the processed surface with an ESCA revealed that the overall Si/N in the depth direction was 1.3.

[0050] Example 2

A SiN film was formed on a silicon wafer (200 mm ϕ) using the apparatus shown in Fig. 3. A parallel plate opposed-type long nozzle was formed by spray-coating each of the electrodes 2 and 3 made of aluminum with the solid dielectric 4 made of alumina, so that a slit of the plasma outlet had a gap of 2 mm, the distance till the silicon wafer was 5 mm, and a DC voltage could be applied to the silicon wafer side,

[0051]

A 100% nitrogen gas was introduced as a processing gas from the gas inlet 5 at a flow rate of 10 l/min, and a voltage of 20 kV with a frequency of 20 kHz and with a pulse waveform and a pulse rise/fall time of 5 μ s shown in Fig. 1(a) was applied to a space between the electrodes 2 and 3 to cause electric discharge under a pressure of 95 kPa (atmospheric pressure), so that plasma was generated. Further, a DC voltage of 300 V was applied to the substrate side, and the resulting plasma was blown to the silicon wafer heated to 400°C so as to process the silicon wafer.

[0052]

It was confirmed that a SiN film with a thickness of 1 nm was formed on the processed silicon wafer in a processing time of 20 minutes. The observation of the

processed surface with an ESCA revealed that the overall Si/N in the depth direction was 1.3.

[0053] Example 3

A silicon wafer was processed in the same way as in Example 1 except that a mixed gas containing 5% nitrogen gas by volume and 95% xenon gas by volume was used as the processing gas. A Si film with a thickness of 1 nm was formed in a processing time of 60 minutes.

As is evident from the aforementioned examples, Hironari only discloses using a 100% nitrogen gas (i.e., 0% inert gas) in Examples 1 and 2 and using a mixed gas containing 5% nitrogen gas by volume and 95% xenon gas (inert gas) by volume in Embodiment 3.

In addition, Hironari does not take into account the content of oxygen or oxide in the nitrogen gas.

Furthermore, “Example 1” and “Example 2” only show that the processing time differs depending on whether a DC voltage of 300 V is applied to the substrate side or not. Processing conditions such as pressure are the same in “Example 1” and “Example 2.”

Thus, there is nothing in Hironari which discloses or suggests the method of amended claim 1.

(2) Regarding U.S. Patent 4,671,813 to Yoshino:

Yoshino is directed to an apparatus for producing highly pure nitrogen gas in the electronics industry, noting that conventional nitrogen gas-producing apparatus of the low temperature separation method and the PSA method do not provide the requisite purity (Abstract). In the “PRIOR ART” section, Yoshino goes on to explain that for use in the electronics industry, two methods are available for removing oxygen as an impurity from

nitrogen gas produced by the low temperature separation method (col. 1, lines 26-39). That is, Yoshino discloses that nitrogen produced by the low temperature separation method cannot be used as is in the electronics industry, but rather must be further treated to remove the oxygen impurity. Bridging cols. 2-3, Yoshino discloses that nitrogen gas produced by the PSA method must also be treated, for example, using a molecular sieve, so as to remove the oxygen impurity before it can be used (col. 2, lines 47-55).

The reason for rejection was that it would have been obvious to use the nitrogen gas of Yoshino containing an oxygen impurity as the nitrogen-containing gas in the technique of Hironari so as to form an oxynitride.

However, the passage at col. 5, lines 60 - col. 6, line 20, contrary to the Examiner's assertion, does not disclose that nitrogen gas used in the electronics industry contains from 5 to 1,000 ppm of oxygen impurity. Rather, once read carefully, Yoshino discloses that conventional apparatus, PSA type in particular, are not applicable as they are (that is, without further purification) to the electronics industry where highly pure nitrogen gas is required. Yoshino at the top of col. 6 goes on to explain that for use in the electronics industry, it is necessary to provide a refining apparatus separately (i.e., separate from the low temperature or PSA apparatus) to remove oxygen impurity in nitrogen gas, for example, by adding hydrogen and by combining oxygen with hydrogen into H₂O. Yoshino at col. 6, lines 13-16 then explains that nitrogen gas produced by his apparatus provides highly pure nitrogen which can be used for the electronics industry as is. Even Yoshino teaches treating the nitrogen gas thus prepared prior to use with adsorbing means incorporating adsorbent which can selectively adsorb oxygen (and carbon monoxide) at ultra low temperature. See claim 3 of Yoshino.

Thus, there is no apparent reason in Yoshino which would lead one of ordinary skill in the art to employ nitrogen gas containing an oxygen impurity in an amount of 5 to 1,000 ppm for use in the electronics industry (e.g., in a plasma apparatus) as suggested by the Examiner. Rather, Yoshino teaches that nitrogen gas containing such impurities is not suitable for use in the electronics industry.

For the above reasons, it is respectfully submitted that the amended claims are patentable over the cited prior art, and withdrawal of the foregoing rejection under 35 U.S.C. § 103(a) is respectfully requested.

Withdrawal of all rejections and allowance of claims 1, 3, 5-7, 9, 10, 12, 14, 16, 19, 21, 27 and 28 is earnestly solicited.

In the event that the Examiner believes that it may be helpful to advance the prosecution of this application, the Examiner is invited to contact the undersigned at the local Washington, D.C. telephone number indicated below.

The USPTO is directed and authorized to charge all required fees, except for the Issue Fee and the Publication Fee, to Deposit Account No. 19-4880. Please also credit any overpayments to said Deposit Account.

Respectfully submitted,



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